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DEVELOPMENTS IN COAL MINE FIRE CONTROL

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DEVELOPMENTS IN COAL MINE FIRE CONTROL

by

R.N. Chakravorty* and R.J. Kolada*

ABSTRACT

Coal mine fires present a very serious hazard to both the safety and the economic health of mining operations. Although the mining industry has considerable knowledge and experience in combating mine fires major losses and damage still frequently occur. Consequently the mining industry is striving to develop and improve their fire fighting capabilities and this endeavour presents a major challenge to mining research organizations.

This paper reviews current methods of coal mine fire control and discusses recent developments. Particular emphasis is given to the prevention and detection of spontaneous combustion and to the relatively new techniques of using inert gases to extinguish fires.

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DÉVELOPPEMENTS DE LA LUTTE CONTRE LES INCENDIES DANS LES MINES DE CHARBON

par

R.N. Chakravorty* et R.J. Kolada*

RÉSUMÉ

Les incendies dans les mines de charbon sont une menace sérieuse à la sécurité et à la viabilité économique des opérations minières. Bien que l'industrie minière possède une connaissance et une expérience considérables de la lutte contre les incendies dans les mines, il arrive encore fréquemment que des pertes et des dommages importants se produisent. Par conséquent, l'industrie minière s'efforce de mettre au point et d'améliorer les moyens qu'elle possède pour lutter contre les incendies, et cet effort présente un défi majeur aux organisations de recherche minière.

Ce rapport fait une revue des méthodes de lutte contre les incendies et examine les développements récents dans ce domaine. Il met l'accent sur la prévention et la détection de la combustion spontanée et sur les techniques relativement nouvelles d'extinction des incendies à l'aide de gaz inertes.

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INTRODUCTION

Coal mine fires have caused considerable loss of life and the closure of numerous mines. Serious fires often result in the closure of a part of the mine and the sterilization of large quantities of reserves. In addition, there is invariably a significant loss in production and of equipment. In spite of extensive research the control of mine fires still remains a major challenge to mining engineers and researchers. The rapid and continuing evolution of mine fire control techniques is of increasing importance due to the introduction of advanced mining technology. This has given rise to new sources of ignition and requires the development of novel methods of fire fighting and prevention.

Generally, there are two basic types of mine fires: gob fires and open fires. It has been observed that in the case of spontaneous combustion the resulting fire generally migrates towards the source of oxygen. Thus many gob fires caused by spontaneous combustion may break out into the open depending on the location and geometry of the mine. The combination of the deep seated gob fire and an open fire presents a serious situation. Open fires may vary from small localized occurrences to severe situations where the combustion zone rapidly travels unchecked along a roadway.

Since prevention is better than cure the major emphasis has, in the past, been placed on the elimination of ignition sources. In the event of a severe fire prompt decisive action is essential. Factors to be considered would include the location, type and intensity of the fire, the ventilation system and above all the risk to the lives of the work force. The priority in all fire control methods should be to secure the safety of men and to bring the fire under control with the minimum risk to the fire fighters.

As the time during which a fire remains undetected increases, the probability of successfully extinguishing it decreases, and the resulting damage to the mine that can be expected will invariably increase. However, early detection of a fire can reduce the task of fighting the fire to no more than a minor nuisance causing little interruption to production. Thus in recent years considerable research has been conducted into developing early detection systems capable of recognising the gaseous products which result from the early stages of fire or heating.

CONVENTIONAL FIRE CONTROL METHODS

The most commonly used techniques for fire control are as follows:

a) remove the burning or heated coal
b) smother the fire by depriving it of oxygen.
c) isolate the fire by fire proof zones that do not contain any combustible material
d) extinquish the fire with substances such as powder or water which inerts the surface of the burning material.

Removal

Digging out the heated or burning area is the quickest method usually effective on surface coal dumps. However, it is also the most hazardous and requires movement of a considerable amount of hot material. Other major disadvantages of this method are high handling costs and requirement of large areas for spreading out the hot material to cool. In underground mines the method is usually adopted when a fire or heating is thought to be near the roadside. Digging out does not always prove effective as often the zone of heating is frequently more widespread than first anticipated and the risk of dug out material suddenly bursting into flames exists.

Smothering

There are a number of conventional fire fighting methods designed to starve the burning area of oxygen in order to prevent further combustion. With all of these techniques the heated material must be smothered for a period of time sufficient to allow the material to cool down to normal temperatures. The cool down period may take many years over which constant maintenance and attention are necessary to ensure that air supply to the affected zone is not re-established. This often proves to be an expensive undertaking.

On surface coal dumps bulldozers may be used to compact layers of coal over the surface of the dump. A less frequently used method is to spread material such as tar macadam over the dump. In underground mines the roadways within the vicinity of the heating can be lined with a material such as plaster or grout. This is often done along the gob side of a roadway where the coal is heavily fractured and prone to air leakage. Air may be fed to a heating through fractures in the strata and these passages may be blocked off by injecting a sealing compound such as cement and flyash through boreholes at high pressures. Another method of smothering a fire is to construct stoppings in all of the roadways leading to or from the fire area. This method is safe and effective. However it is usually used as a last resort since large areas of reserves are often sterilized and new areas will require development work to replace the lost production.

Isolation

Fire proof stretches of roadways may be constructed with the aim of containing any major fire to certain sections of the mine or roadway. Because of thermal transmission by the ventilation, such zones typically have to be 100 to 200 metres in length and must be completely free of combustible material including flammable conveyor belting. This may be difficult to achieve due to the deposition of coal dust but the technique may justify further research.

Extinguishing

Extinguishing with substances such as water or powder is normally only applicable to open fires. Since fire fighters must approach the fire to apply the extinguishing medium this technique is obviously very hazardous. The effectiveness of the technique is dependant on the rate of quenching being greater than the spread of the fire. Therefore early detection and application is essential for success with this technique.

Flooding

Flooding an underground coal mine with water is another method occasionally used to control and prevent the spread of a fire. If the seat of the fire is on the dip side and the strata is strong enough to withstand the hydrostatic pressures this method can prove satisfactory. Availability of adequate water supplies at the mine site, the cost of dewatering the mine and most importantly the possible loss of expensive mining equipment often precludes the use of this method in favour of others.

CONTROL OF ABANDONED MINE FIRES

Abandoned mine fires are difficult to control because of the lack of accessibility and the large area over which the fire may exist. The lack of accessibility precludes the erection of stoppings in the same manner as for an operating mine. In the case where the depth of cover is shallow fissures from the coal seam to the surface may develop through which air can flow to maintain the fire. Isolation of such fires can be achieved by construction of a trench from the surface to the level below the coal seam and then backfilling the trench with an inert material. Alternatively a fire barrier can be constructed by injecting wet or dry fly ash or any other inert material into the mine entries through boreholes from the surface. The

surface above the isolated area is then cleaned, ploughed and compacted. The objective is to prevent 'atmospheric breathing', that is to prevent the flow of air through cracks and crevices that occur due to changes in atmospheric pressure and thermally induced circulation flows. Here again heat dissipation is slow and requires extensive maintenance over a number of years. The greatest disadvantage with surface trenching and inerting techniques for shallow underground fires is the handling of enormous quantities of material. A sixty foot isolation trench would require 180,000 tons for every 1000 foot length [1].

The U.S. Bureau of Mines recently conducted elaborate tests at the Calamity Hollow mine fire project to study the effectiveness of controlled burnout as a potential method for fire control. Also, the Bureau investigated the use of water injection with fume exhaustion as a method for cooling large underground fire zones. These techniques are discussed in more detail later in the text.

MINE FIRES CAUSED BY SPONTANEOUS COMBUSTION

A survey of incidences in different countries has established that 75% to 85% of mine fires are caused by spontaneous combustion[2]. Obviously, from these figures it is apparent that the prevention and control of spontaneous combustion is of major importance in the effective control of mine fires.

Factors Influencing Spontaneous Combustion

The spontaneous heating of coal is an extremely complex process which depends on both the intrinsic properties of the coal and the external influence of the mining conditions. There is no simple method by which it is possible to predict whether a particular method of mining applied to a

particular seam will result in spontaneous combustion. Under favorable conditions of heat accumulation, spontaneous combustion can occur with any type of coal and there has been numerous instances of this occurring to coal of low moisture, sulphur and volatile content which is usually considered to be relatively safe.

It has been observed that lignite and sub bituminous coals oxidize fairly rapidly, whereas oxidation proceeds relatively slowly with higher rank coals (i.e. low volatile bituminous coal and anthracite). Petrographic composition also plays a significant role in the oxidation process. Exinite has a much greater oxidation rate particularly at temperatures above 75 degrees celsius compared to vitrinite and inertinite. The exposed surface area of coal significantly influences the rate of oxidation and, as a result, the friable coals producing large amounts of fines are more vulnerable to spontaneous combustion. Certain forms of pyrite if present in coal will help in the oxidation process by causing a disintergration of the coal mass and thus increases the surface area of the coal open to oxidation.

Moisture plays a very complex role in the low temperature oxidation of coal. Both the inherent moisture in the coal and the moisture in the atmosphere are determining factors in the occurrence of spontaneous combustion. Wetting of partially dry coal of high inherent moisture often results in spontaneous heating. Heat lost by evaporation of moisture is three to four times as much as that generated by oxidation, and cooling of the coal will occur if the air is dry or unsaturated. Therefore at low temperatures, evaporation or desorption of moisture from coal will have an inhibiting effect on spontaneous heating. On the other hand, condensation of moisture is likely to liberate much more heat than that released by oxidation.

Mining may cause fractures between closely spaced seams through which air can flow. In this situation spontaneous combustion can occur in adjacent worked out seams. Similarly, areas around faults constitute lines of weakness resulting in the leakage of air. The roadside packs containing fine coal pose the greatest risk in underground mining. Air leakage through fissured seams or pillars have caused heating in coals liable to spontaneous combustion.

Fractures developed in solid coal such as at the corner of pillars or at air crossings are always a potential source of danger. Doors and regulators unless carefully installed can also cause air leakage through fractures in the solid coal in the local vicinity, due to the increased pressure differential. This effect of increased pressure differential increasing the risk of heating is also applicable to coal between roadways that are relatively close to each other. Table 1. summarizes the critical factors influencing spontaneous combustion in coal mines. Where a number of these conditions exist the mine will naturally be at a greater risk. [3]

The Prevention and Control of Spontaneous Combustion

The layout of a mine is the single most important factor for the prevention of heating. Working places should be designed so that each section can be isolated quickly without affecting production in others. Sites for preparatory seals should be marked during planning. The retreat method of working is preferred because of the advantage that the gob is not subjected to a large difference in ventilation pressure. In planning against spontaneous combustion the pillars should be designed so that they are capable of resisting excessive crush. The panel system of working is preferred particularly for mining coals susceptible to spontaneous heating. The size of the panel should be decided on the basis of the incubation period and the rate of extraction.

Mine planning should incorporate salvaging of equipment and sealing of the district without delay as most heatings occur when a particular panel is about to be finished.

Control of air leakage is the key to controlling spontaneous combustion. The observance of the following would prove useful:

(a) Pressure absorption rate should be maintained even
(b) Localized uncontrolled pressure difference should be avoided
(c) Unnecessary stopping and starting of ventilation fans should be discouraged

Table 1 - Critical factors contributing to spontaneous combustion

Intrinsic factors which cannont be controlled		Extrinsic factors which can be conntrolled
Coal properties	Geological features	Mining practices
a. High volatile matter	a. Thick seams	a. Accumulation of fine coal in worked out areas
b. High moisture	b. Presence of inferior pyrite bands and carbonaceous shale	b. Leaving roof and floor coal during mining
c. High pyrite	c. Presence of faults	c. Poor maintenance of roadways and old districts
d. High exinite	d. Weak and disturbed strata conditions	d. Inadequate measures to prevent air leakage through air crossings, doors, gateside pack
e. High friability	e. High strata temperature	e. Caving to surface under shallow overburden
		f. Mulit-seam working close proximity
		g. Poor ventilation management

(d) The ventilation pressure across seals should be balanced

(e) Ventilation efficiency of a particular area should be monitored periodically and causes of leakage should be investigated

Sealants should be used in all areas where there is likelihood of air leakage eg.in gate side packs, fractured pillars and also for consolidating roof coal, coal mass around doors and air-crossings. Suitable sealants are calcium sulphate based gypsyl, mandoseal, latex, liquid cement and sodium silicate.

Various inhibitors for control of spontaneous combusion have been tried with limited success. Chamberlain and Hall (4) concluded that a borate solution or montan powder sprayed in the gob area or infused into a low rank coal would reduce the possibility of spontaneous combustion. Figure 1 summarizes the precautionary measures recommended for the prevention of spontaneous combustion (5).

EARLY DETECTION OF HEATING

The early recognition of a heating is absolutely necessary for the prevention and control of mine fires. By detecting a fire at an early stage it is possible to save a mining operation from considerable loss and damage. Therefore, in recent years, great emphasis has been given to develop methods for early detection of fire and heatings.

The time period between the onset of heating to the outbreak of fire can be considerable. This delay provides the oportunity for early detection systems to identify heatings and contain them before a open fire can occur. Depending on the type of coal, and the external influences acting upon it, this time period can vary between a few days to a few months.

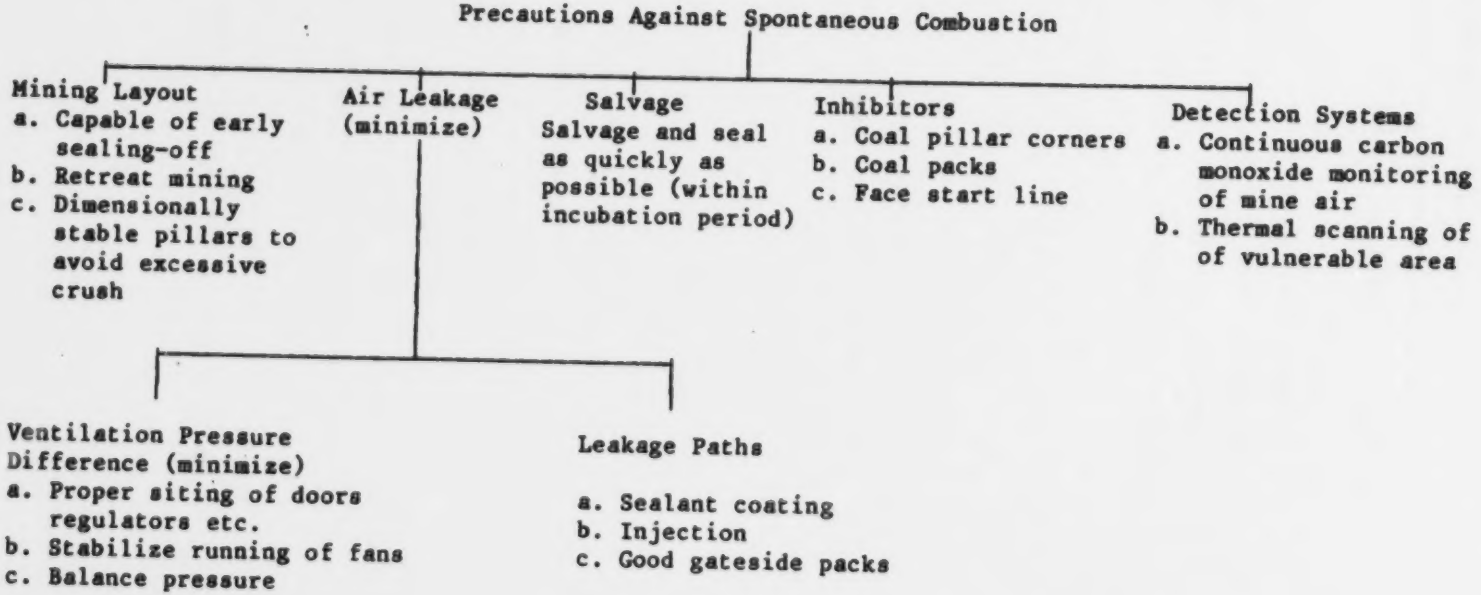

Precautions Against Spontaneous Combustion
Mining Layout
a. Capable of early sealing-off
b. Retreat mining
c. Dimensionally stable pillars to avoid excessive crush
Air Leakage (minimize)
Salvage
Salvage and seal as quickly as possible (within incubation period)
Inhibitors
a. Coal pillar corners
b. Coal packs
c. Face start line
Detection Systems
a. Continuous carbon monoxide monitoring of mine air
b. Thermal scanning of of vulnerable area
Ventilation Pressure Difference (minimize)
a. Proper siting of doors regulators etc.
b. Stabilize running of fans
c. Balance pressure
Leakage Paths
a. Sealant coating
b. Injection
c. Good gateside packs

Fig. 1 - Precautionary measures recommended for the prevention and control of spontaneous combustion

Methods of Early Detection

Extensive research in many countries has indicated that the identification of the combustion products produced by heating is the best approach for early detection. The main gaseous products resulting from low temperature oxidation of coal are carbon dioxide, carbon monoxide and water vapour. In underground operations carbon dioxide is generally considered to be unsuitable for studying the progress of a heating as there are other sources than fire from which this gas may originate. On the other hand carbon monoxide has proved to be a more specific product of combustion particularly during the low temperature oxidation of coal. The "Graham's method" of early detection of heating is based on the carbon monoxide/oxygen ratio of the mine atmosphere in return airways. Over the years many heatings have been detected at an early stage using this method. The greatest advantage of measuring the carbon monoxide/oxygen deficiency ratio is the fact that it is independant of any dilution by fresh air. A rising trend in the value of the deficiency ratio invariably indicates the onset of a heating.

It has been observed that the production of carbon monoxide alone cannot reliably indicate the onset of a heating unless it is accompanied by the production of ethylene. Tashiro et all concluded that increase in ethlyene and the alkane ratio ($CH_4/C4H_{10}$) in mine air are a better indicator than an increasing trend in the carbon monoxide level alone [6]. Research by Chamberlain and co-workers [7] showed that although a large number of saturated and unsaturated hydrocarbons, such as methane, ethane, ethlyene, and acetlyene are produced during the early stages of heating, none of the gases provide a better alternative to carbon monoxide for the detection of a heating. CANMET studies on Canadian coals also indicated similar results [8]. It was observed that carbon monoxide is produced in detectable amounts even at a temperature of 70 degrees Celcius.

Continuous Monitoring of Mine Air

The use of automatic computerized ventilation monitoring systems in coal mines has played a major role in substantially improving safety records. One of the major reasons for this success is due to the ability of the monitoring system to detect a heating at an early stage.

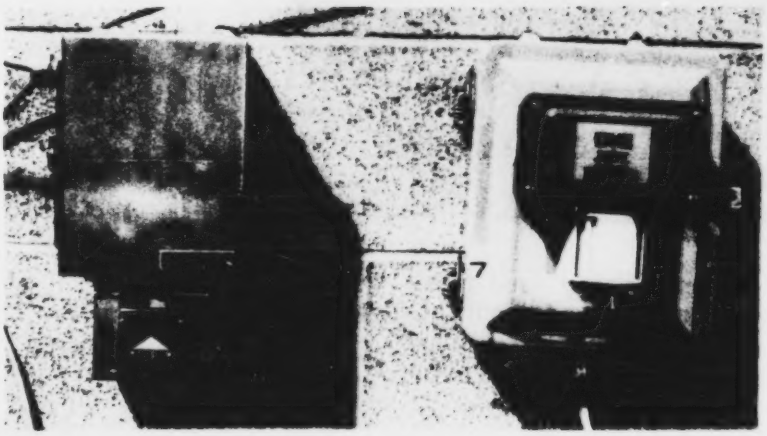
There are two main types of ventilation monitoring systems in use, namely, the tube bundle and telemetry system. The tube bundle system operates by drawing air from strategic locations into individual tubes. The tubes are connected to the mine surface where the mine air is analysed for carbon dioxide, carbon monoxide, methane, oxygen etc. The telemetry system uses sensors to analyse the mine air at strategic locations. The information from the transducers is passed to an outstation which can provide such functions as analogue to digital conversion, multiplexing, signal conditioning and buffering for storing the data. When instructed by the computer the outstation will transmit the stored data through the connecting cable to the computer on the mine surface for processing. The transmission of data by telemetry is almost instantaneous whereas the time between taking and processing a sample with a tube bundle is often as long as 30 minutes. Consequently tube bundle systems are now being gradually replaced with telemetry systems.

One of the major advantages of automated monitoring systems arises because of the capability of the computer to process large quantities of data, indicate when preset alarm limits have been exceeded and provide shift reports trend analysis etc, and all these functions can be achieved with almost no human intervention. A typical computerized environmental monitoring system is shown in Figure 2.

Thermal Methods

Infra-red imagers and scanners have been developed in recent years which can provide a detailed thermal picture of the entire scene within the view of the imager. This picture has high resolution and can show small

CRT, Data Printers and the Processor Unit



Carbon Monoxide and Methane Sensors

Figure 2. Coal mine environmental monitoring system

thermal temperature differences between closely positioned objects. It is thus capable of locating hot spots on a large body very rapidly and accurately. The imagers can also be fitted with a camera to take photographs or video film and thermal image data can be stored on floppy discs for computerized trend analysis.

A number of heatings have been successfully identified using infra-red scanning technology [9]. Figure 3 shows the infra-red scanner being used for a thermal survey near underground stoppings. Figure 4 shows photographs of hot spots located during a thermal survey in coal outcrop areas and in coal stock piles. In almost all these cases routine visual

inspection did not reveal anything abnormal. The success of this technique depends on the correct interpretation of the thermal anomalies observed during the survey. For the location of heatings in fissured coal pillars, stockpiles and outcrop areas infra-red scanners can be particularly useful.

Figure 3. Infrared scanner being used for a thermal survey near underground stoppings

RECENTLY DEVELOPED TECHNIQUES FOR FIRE CONTROL

In recent years significant advances have been made in the development of fire control techniques.

Sealants

Development of sealants has contributed considerably in the control of air leakage through cracks and fissures, particularly in coal pillars and gate road packs and thereby reducing the incidence of spontaneous heatings. Sealants can be grouped into three main categories; gypsum based, cement based and others. The last group includes sealants incorporating rubber, latex, urea formaldehyde, phenolic resins and bentonite.

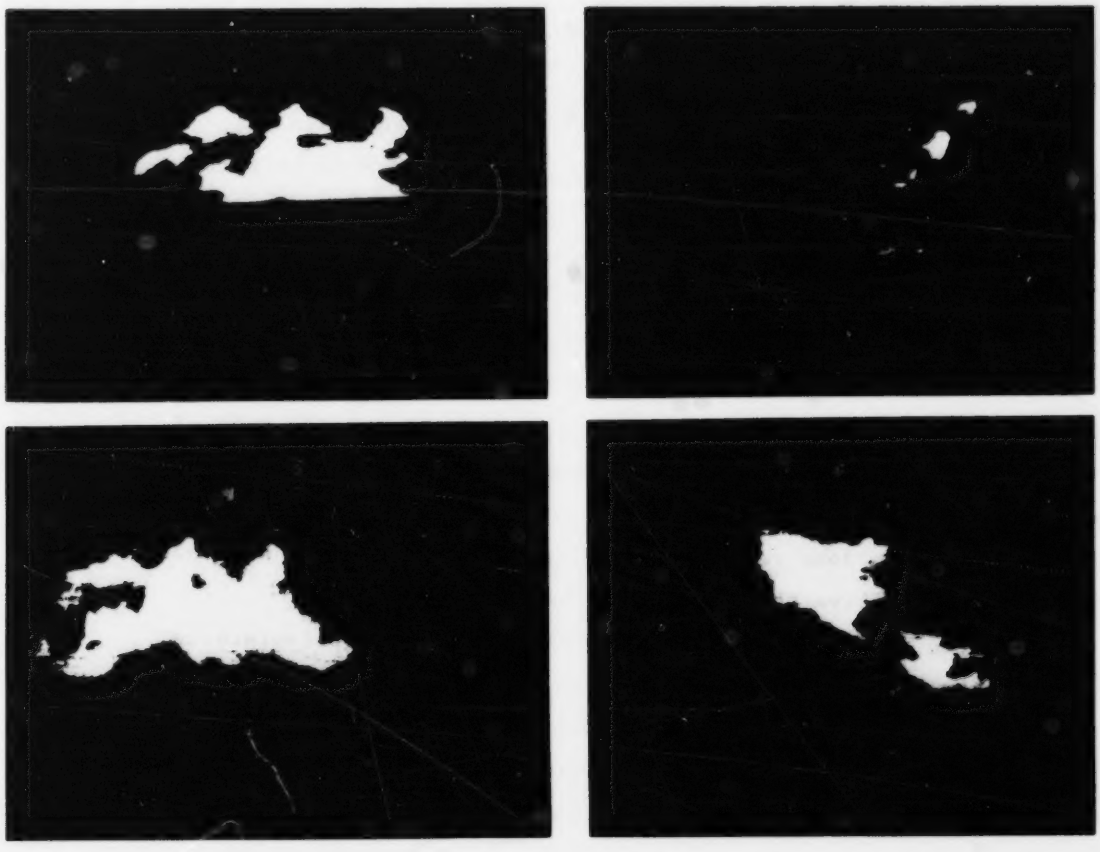


Figure 4. Photographs of hot spots located during a thermal survey in coal outcrop area and in coal stockpiles

Gypsum based sealants usually have materials such as perlite, vermiculite, granulated mineral wool or fiberglass added which helps increase their strength and elasticity. Additives are usually included to extend the natural setting time of about 20 minutes.

The material used for cement based sealants are the same as those normally used in the construction industry such as Portland, Hi-magnesia, oxy-sulphate etc. The properties and uses of these sealants vary from very elastic coatings used as a fire retardant, to concrete compositions used for structural support. Both cement and gypsum can be used with foaming agents for application as a filler.

Latex sealants have only been used on a limited basis since they are difficult to store for any length of time and the surface to be sprayed usually has to be prepared in advance of the two applications that are necessary. Their main advantage is that the sealant will remain airtight while the strata settles.

Urea-formaldehyde foam products have been developed to supercede polyurethane foams that were toxic and flammable. This foam is suitable for filling between and under chocks or between shuttering and the side of the pack. The foam sets in 24 hours and becomes increasingly impermeable under pressure from the strata. Suspected long term health problems have restricted its use in some regions but, where it has been used has shown that it is more cost effective than many other traditional method.

Phenolic resins were also developed to supercede polyurethane foams. One example of this type of foam is 'Mariflex' which consists of a mixture of formo-phenolic resins in a water solution. When mixed with a catalyzer an exothermic reaction occurs which generates an inert gas to foam the product. The foam is both inert and non-flammable.

Bentonite is a natural clay which swells to many times its original volume when mixed with water. Bentonite is a fluid in nature when agitated and gels when allowed to settle. The gel is stable for several months. Bentonite injection is usually used to deal with a specific area and is not normally used for general application.

The choice of a sealant to be used in any particular circumstance is dependant on economics, regulations, the situation to which it is to be applied, the types of sealants that are available and to some extent the preference of the mine operator. The subject of sealants has been discussed in detail in a recent CANMET report [10].

THE USE OF INERT GAS FOR THE PREVENTION AND CONTROL OF FIRES

The principle of fire inertisation is to reduce the concentration of oxygen in the atmosphere. In order to prevent the explosion of a methane-air mixture it is necessary to reduce the oxygen content to below 12% by volume. However to prevent spontaneous ignition fires it is necessary to reduce the oxygen content to below 3%, [11].

Major advances have been made in recent years towards the control of mine fires through the use of inert gases. Inertisation makes it possible to continuously recover the fire zone by moving the inert gas discharge point and stoppings forward in stages. This can greatly reduce the time taken to recover a fire zone when compared to the old method of sealing a fire and then waiting long enough for the fire zone to cool adequately before reopening.

Inertisation also eliminates the need for explosion proof stoppings because it is not necessary to reduce the ventilation flow until there is oxygen depletion. Further, rescue team can enter the affected area with breathing apparatus to fight fire using direct means without fear of explosion. The safer environment created is also conducive to better and more effective work by the rescue team during fire fighting.

In most applications to date nitrogen has been used for inerting,however, carbon dioxide and generators which produce oxygen free exhaust gases have also been found to be effective.

Nitrogen

During the mining of coal seams that are prone to spontaneous combustion the oxidation process in the gob can be limited without imposing constraints to the mining process. This is achieved by continuously injecting nitrogen at a slow rate into the gob area (usually well below 100 m^3/min) and by ensuring that leakage paths into the gate roads are minimized. This technique has been used in French mines with remarkable success.[11, 12]

In the event of a fire outbreak the fire zone can be stopped off and nitrogen discharged into the area at, usually, between 100 and 300 m^3/min. Typically the intake side is gradually stopped off first and the flow of nitrogen is regulated to compensate for the reduced airflow. As the airflow is gradually restricted by the stopping, the nitrogen flow is increased keeping the ventilation as stable as possible and preventing methane concentrations in the return from rising above 3% by volume. When the risk to personnel in the return is considered acceptably low the return stopping can be constructed.

One of the essential conditions for the successful application of nitrogen is that it should be quickly applied. In Germany for example each mine has an inertisation plan that enables them to apply nitrogen to a fire within four to twelve hours after detection. Kock and Linberg have described three excellent examples of fighting fires with nitrogen in German mines.[11]

Most mines in France are equipped with facilities that can enable the use of nitrogen inertization with minimum of delay. These facitities include all the necessary connections for a nitrogen tank and portable evaporator. Prior agreements exist with nitrogen manufacturers to promptly deliver the tank and evaporator when required. Typical underground coal mine fire control with inerting systems is shown in Figure 5. Collieries in the Lorraine basin in France are connected to an industrial nitrogen supply network which was found to be less expensive, [12].

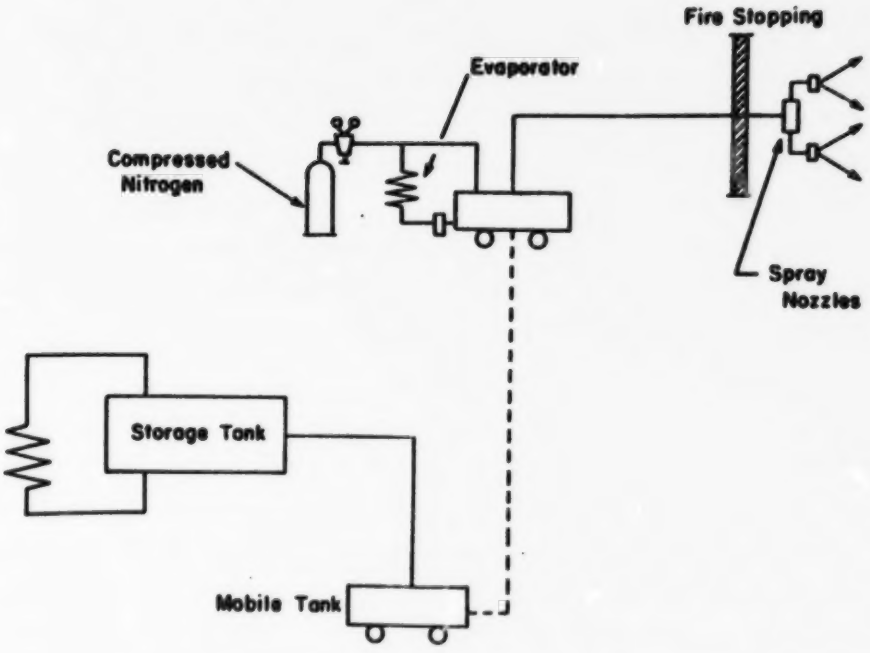


Figure 5. Underground coal mine fire control with inerting systems

The direct cost of fighting a fire with nitrogen or carbon dioxide can be high. For example the cost of fighting a fire at one British mine with carbon dioxide was about a million dollars. However, this resulted in a savings of equipment worth seven million dollars. In Germany during the period 1974 to July 1985 the method was used 74 times and a total of 240 million m^3 of nitrogen was used. As a result 65 sets of face equipment was saved, an output of 70,000 t/d was preserved and in only three instances was it impossible to get a clear cut success [11, 13].

Carbon Dioxide

Carbon dioxide may be used instead of nitrogen and is occasionally chosen in preference to nitrogen particularly in situations where the location of the heating is at the bottom of a steeply sloping area or at the bottom of a shaft. The high density of carbon dioxide directs the gas migration to the area of the heating.

In Canada there have been a number of explosions and fires in coal storage silos due to the accumulation of methane and the outbreak of spontaneous combusion. This has resulted in some mine operators installing tanks of carbon dioxide next to these silos so that any heating may be quickly extinguished.

Use of inert gas in dealing with underground fire at No. 26 Collery in Sydney, Nova Scotia also proved useful during sealing operations and in subsequent attempts to recover the mine.

Inert Gas Generators

Most inert gas generators consist of an aero jet engine with an afterburner. The inert combustion products from this jet are passed through a cooling system and discharged into the fire area through a duct. This system of generating an inert gas is cheaper than with carbon dioxide or nitrogen and can be produced at a greater flow rate than generally obtained with other inert gas systems. However, there are a number of disadvantages associated with this method which are often sufficient to discourage its use in preference to one of the other types already described. These disadvantages include; requires large volumes of cooling water; does not comply with flameproof requirements of most jurisdictions; the rate of generation and delivery is difficult to control and due to the low delivery pressure it is necessary to situate the generator close to the fire.

The design and method of use of inert gas generators are still being improved. For example generators are being designed to use nitrogen for evaporative cooling. This increases the proportion of nitrogen in the product and enables the delivery duct to be purged before the generator is put into operation. Consideration is also being given to modifying the generators to increase the delivery pressure so that they may be operated from the surface while delivering the inert gas to the fire through boreholes, [13].

Once the mine air in the vicinity of a heating or fire is flushed with inert gas it is advisable to send a rescue team equipped with breathing apparatus to investigate the condition of the area before any effort to recover the mine is attempted. An absence of smoke or oxygen in the area will confirm that the fire is extinquished though red hot coal can still exist shortly after inerting. Different aspects of inertization as a means of fire control are discussed in detail in a recent CANMET report [13].

FOAM AS A FIRE BARRIER

Mine roadways may be remotely sealed by injecting flyash or similar inert materials from surface boreholes using an inert gas such as nitrogen as a transporting medium. One of the major difficulties that limits the effectiveness of this method is ensuring that the injected material forms an airtight seal against the top of the roadway. To overcome this difficulty the U.S. Bureau of mines has recently developed a technique of injecting foam into the roadway to ensure a good seal, after the injection of the flyash.

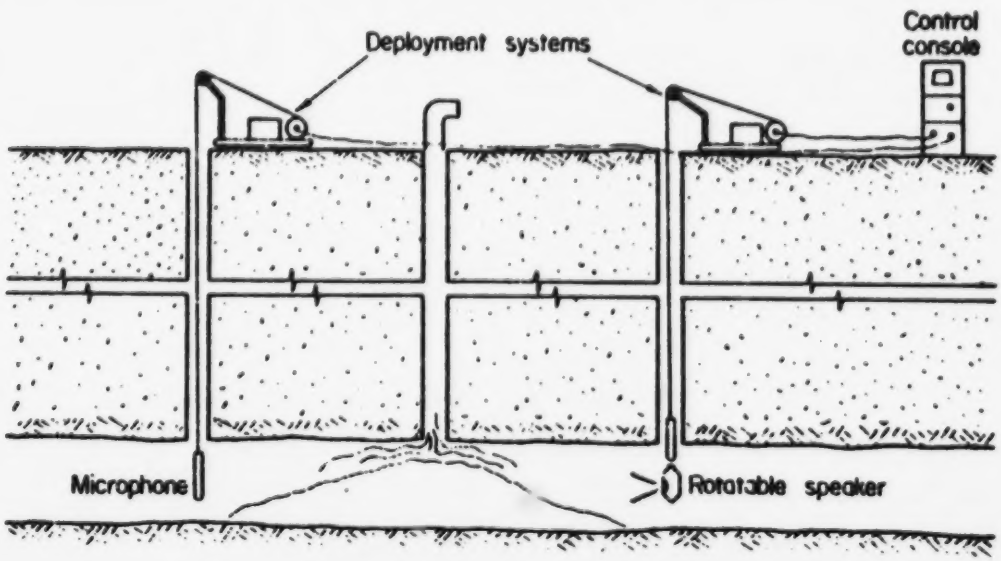


Figure 6. An acoustic seal checker system in operation

The integrity of the seal is then checked acoustically by lowering a high intensity speaker through a borehole on one side of the seal and a microphone on the other. Figure 6 illustrates an acoustic seal checker system in operation. This technique has found useful application in both abandoned as well as operational mines, [14].

Some investigations have also been carried out to evaluate the use of high expansion foam for automatic conveyor belt fire extinguishers. However there are a number of disadvantages to this method due to the slow delivery rate and the possible formation of gaps at the roof especially in roadways with high ventilation velocity.

CONTROLLED BURNOUT AND QUENCHING

The technique of isolating an area of a mine that is on fire and then injecting water to quench it, is not new and has been attempted many times in the past. However, this method has not achieved a great deal of success.

To extinguish a fire by this method it is necessary to distribute the water over the entire zone of burning and to prevent the water migrating into areas outside of the fire zone. Although the water may cool the burning material, the sensible heat is still trapped and can spread through the isolated area to other parts of the mine. To prevent reignition of the fire all the burning and heated material must be cooled to a relatively low temperature. This can take a very long time if there is no provision for a pathway through which the heat can escape.

To overcome the difficulties associated with the conventional method the U.S. Bureau of mines proposed and tested a method known as WIFE (water injection fume exhaustion). Considerable success was achieved with this method, by the Bureau, in a full scale test at the Calamity Hollow Mine Fire Project. [15]. In this method the fire zone is isolated in the ususal manner

but provision is made for ventilating the fire zone to encourage burning. The object of this is to attempt to completely burn all of the combustibles in the fire zone and thereby reduce the risk of re-ignition when the area is dug out. The second part of this method is to inject water while still maintaining the ventilation flow to the area. In this way the fire zone may be quenched and the heat produced can be removed from the mine.

CONCLUSIONS

The use of early warning systems in underground coal mines appears to be the most effective method for the prevention and control of mine fires. The design and installation of such systems should form an integral part of mine planning from the initial development and throughout the life of the mine. A combination of infra-red thermography and continuous monitoring of carbon monoxide should be able to provide adequate warning of heatings before a fire can break out.

Application of sealants to prevent air leakage should be practiced widely in mines prone to spontaneous heatings. This method should significantly reduce the number and extent of such heatings.

Use of inert gases has proved to be useful for both the control of mine fires and for the neutralization of explosive or flammable atmospheres that can occur during fire fighting. A steady supply of inert gas into the gob area of seams prone to spontaneous combustion, can prevent heatings within this region from occurring. It is advisable that all coal mines consider suitable emergency planning and preparations including supplies of inert gas so that heatings can be dealt without delay.

The role of the regular work force should not be underestimated. Most fires are controlled and extinguished by bare faced miners. It should be ensured that the workforce has the necessary tools and training so that the first response by on-site people is correct and productive.

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